Acoustic Thermometry of Ocean Climate: Marine Mammal Issues

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SUMMARY

After global warming became a concern in the mid-1950s, researchers proposed measuring deep ocean temperatures to reveal any significant trends in core ocean warming. Acoustic thermometry can detect changes in ocean temperature by receiving low-frequency sounds transmitted across an ocean basin because the speed of sound is proportional to water temperature.

Acoustic Thermometry of Ocean Climate, or ATOC, is an international program involving 11 institutions in seven nations. It is designed as a 30-month "proof-of-concept" project to provide data on possible global climate change, with funding provided by the U.S. Department of Defense. A Marine Mammal Research Program (MMRP) was established as part of ATOC, to assess the effects of ATOC sound signals on marine mammals. The proposed ATOC sources will be located 15 kilometers off the coast of Kauai, Hawaii, and near the Pioneer Seamount, approximately 88 kilometers west of Point Pillar, California. The California source was originally proposed 40 kilometers off the coast of Point Sur, California, in the Monterey Bay National Marine Sanctuary, but the Sanctuaries and Reserves Division of the National Oceanic and Atmospheric Administration did not concur in this proposal.

A debate has arisen over ATOC's impact on marine mammals versus the benefits of better global warming information derived from ATOC. Among the concerns are questions regarding the effects of low-frequency sound (below 100 Hertz) on marine mammals, and the baseline data available on marine mammals near the proposed source locations. Moreover, concerns have been raised about baseline data available for other marine biota, such as fish and sea turtles. In response to concerns expressed by the public, environmental groups, and scientists, as well as by Members of Congress, the National Marine Fisheries Service (NMFS) held a series of public hearings on the Marine Mammal Protection Act (MMPA) permit applications by Scripps Institution of Oceanography for ATOC. Consequently, ATOC was delayed until draft environmental impact statements (EISs) could be prepared. The Office of Naval Research funded a National Research Council (NRC) investigation of current knowledge and research needs with respect to the effects of low-frequency sound on marine mammals. The NRC report, released in March 1994, concluded that the data were insufficient to determine the possible effects of low-frequency sound on marine mammals. The NRC report emphasized the need for further studies on wild marine mammal behavior and marine mammal audition, and a review of the MMPA scientific research permitting process.

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The lack of information regarding the effects of low-frequency sound on marine mammals is evident. Consultation with NMFS, the Marine Mammal Commission (MMC), and the MMRP Advisory Board led to including mitigation measures in the draft EISs to alleviate potential harm to marine mammals. MMRP and other component studies are expected to provide substantive information on the effects of low-frequency sounds on marine mammals.

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INTRODUCTION

Global warming became a concern in the mid-1950s. The evidence for global warming would be expected to show in a wide variety of indirect and direct observations: an increase in atmospheric carbon dioxide (CO2) levels as well as other trace gases such as methane, nitrous oxide, and chlorofluorocarbons (CFCs), an increase in atmosphere temperature, widespread retreat of glaciers, changes in isotope ratios in plant biomass, and ecosystem changes attributable to warming trends.(2) Acoustic thermometry is a signal processing technique that may provide additional data for detecting any increase in core ocean temperatures. Acoustic thermometry detects changes in ocean temperature by receiving low-frequency sounds (below 100 Hertz) transmitted across ocean basins, because the speed of sound increases as water temperature rises.(3) Acoustic thermometry might be more accurate than other means for measuring global warming because of its wide geographic (ocean basins) scope and year-round coverage. However, controversy has developed over projects, such as the Acoustic Thermometry of Ocean Climate (ATOC) project, which apply this technique.(4)

Concerns were expressed that ATOC may harm marine mammals protected under the Marine Mammal Protection Act (MMPA)(5) and the Endangered Species Act (ESA).(6) A debate has arisen over ATOC's impact on marine mammals and other marine species versus the benefits of additional global warming information.(7) Since some marine mammals use low-frequency sound in feeding, navigating, and communicating, the potential impact of low-frequency sounds of human origin on these species may range from no impact to subtle changes in behavior, temporary behavioral disturbance, avoidance of important feeding or calving areas, deafness, and possibly death.(8) The primary U.S. responsibility for management of whales and dolphins is delegated under the MMPA to the Secretary of Commerce and administered by the National Marine Fisheries Service (NMFS) within the National Oceanic and Atmospheric Administration (NOAA).(9) An independent Marine Mammal Commission (MMC) was established by Title II of the MMPA to make recommendations to NMFS ensuring that the intents and provisions of the Act are met.

THE SCIENTIFIC QUESTIONS

Has the increase in CO2 levels raised global temperatures?

Since the onset of the industrial revolution in 1860, the level of CO2 in the atmosphere has risen 27 percent. These data were collected from the Mauna Loa Observatory, Hawaii, and Antarctic ice core samples dating back to 1958 and 1740, respectively.(10) The increase of CO2 has been widely attributed to the consumption of fossil fuels and deforestation (11,12) Models based on atmospheric CO2 levels hindcast an average global temperature increase of 1 degree C from 1860-1990; however, actual temperatures appear to have increased only 0.5 degree C.(13) Some researchers have attributed this discrepancy, in part, to the ocean's interaction with the atmosphere, and the ocean's ability to store both heat and CO2.(14) Because of a relatively short atmospheric temperature record, the detection of a trend on the order of 0.5 degree C per century is very difficult; the natural variability in temperature is far too great (+0.4 degree C per decade) to be able to distinguish the predicted trend.(15) Therefore, several more decades of measurement will be required before such a trend can be verified. However, by the time any trend could be verified, many observers fear that it may be too late to alter the consequences (e.g., sea-level rise, with widespread coastal flooding). Thus, alternative, supplemental measures of global climate change are desirable.

Is any long-term increase in atmospheric temperature reflected in oceanic temperature?

Because of the difficulties in assessing with any degree of certainty what climate models can tell us about future atmospheric temperatures, Dr. Walter Munk (Scripps Institution of Oceanography, University of California at San Diego) proposed measuring core ocean temperatures to answer the global warming question. (16) Current methods of measuring ocean temperatures do not provide basin scale averages over a short time period. Sea surface temperature data from satellites are not accurate enough to detect the predicted climate changes in sea surface temperature (0.02 degree C per year) in the presence of large daily, seasonal, and interannual fluctuations. Repeated temperature profiles at point locations, such as thermometer moorings at a depth of one kilometer would require several decades of data to detect the hypothesized temperature change (0.005 degree C per year) and still only yield information for that location that cannot be extrapolated to larger regions.(17) Therefore, Dr. Munk proposed using acoustic thermometry to detect ocean basin scale changes in core ocean temperature, a method developed by Dr. Munk and his colleague, Dr. Carl Wunsch (Massachusetts Institute of Technology), in the 1970s.(18) Sea surface temperature and mooring data are still needed to provide important information for acoustic thermometry models.(19)

ACOUSTIC BACKGROUND

Acoustic thermometry uses a unique phenomenon known as the deep sound channel or SOFAR (SOund Fixing And Ranging) channel. This channel occurs at an average depth of one kilometer where the speed of sound in sea water is slowest (about 1480 meters per second). The sound speed in water depends mainly on temperature and to a lesser extent on pressure and salinity. Sound speed decreases with a decrease in water temperature (5 meters per second per degree C), and it increases with an increase in pressure or depth. Although water temperature (and therefore, sound speed) decreases with depth down to certain level, a point is reached where the effect of pressure overtakes the effect of temperature. Deeper than this point, the speed of sound increases again; the sound channel is formed around this sound-speed minimum. Once sound enters the channel, it remains in the channel until it dissipates: increasing temperature at the upper-bound of the channel causes sound to refract down into the channel, and increasing pressure at the lower-bound of the channel causes sound to refract up into the channel.(20) Sound in the ocean is dissipated primarily by spreading over large areas, surface scattering, and bottom absorption. Bottom absorption occurs via interaction with bottom features (topography). Ionic (salts) absorptive loss also occurs much in the same way light is attenuated by water; thus, lower frequencies travel farther and higher frequencies much less.

Low-frequency sound signals of sufficient strength propagating through the sound channel can be detected across ocean basins.(21) At SOFAR channel depths, an increase in temperature of 0.005 degree C per year leads to an decreased travel time of about 0.2 seconds per year over a 10,000 kilometer path.(22) Acoustic thermometry also yields information about water temperature, currents, and oceanographic features along the sound path. Experiments conducted over the last 12 years reveal the advancement in acoustic thermometry technology.(23) This technique is similar to computerized axial tomography (CAT) scans which give three-dimensional pictures of tissue structures in the human body,(24) and may reveal a possible greenhouse-induced global warming signal as well as information about other oceanographic phenomena, such as El Nino events, that have profound effects on climate.(25) Acoustic thermometry data may also allow comparisons among ocean basins.(26) However, the question remains: Will this technique be able to separate natural variability from any greenhouse signal? While some researchers believe that enough data can be collected in ten years to reveal any significant trends in core ocean warming,(27) others disagree.(28)

HEARD ISLAND FEASIBILITY TEST

In a 1960 experiment, 130 kilograms of TNT were detonated off the coast of Perth, Australia. Hydrophone (underwater microphone) receivers detected sounds generated by the detonation 3.7 hours later near Bermuda, 20,000 kilometers away.(29) In 1988, Dr. Munk reinterpreted the Perth-Bermuda test, leading to his proposed use of sound to measure basin-scale temperature changes.(30)

Dr. Munk's proposal resulted in the Heard Island Feasibility Test (HIFT), to assess the feasibility of acoustic thermometry for long-range monitoring of ocean temperatures. HIFT was conducted from 26-30 January 1991, off the coast of Heard Island. This uninhabited volcanic island is located near Antarctica, midway between Africa and Australia. The location was selected because of the sound channel's close proximity to the surface (175 meters), as well as the multiple, unimpeded paths to receiving stations on both U.S. coasts, 18,000 kilometers away.(31) HIFT was jointly funded by the Department of Energy, NOAA, the National Science Foundation, and the Office of Naval Research (ONR) for approximately $1.7 million.(32) Permits were deemed necessary after various researchers and environmental groups raised concerns that marine mammals might be harmed.(33) Both NOAA and Australia's Department of Environment determined that full environmental impact statements (EISs) were not required.(34) A U.S. scientific research permit in accordance with §104(c)(3) of the MMPA was approved by NMFS after a 30-day public review period and consultation with MMC. NMFS and Australia's National Parks and Wildlife Service issued permits one week and one day, respectively, prior to HIFT.(35)

The HIFT signals were centered at a frequency of 57 Hertz, and were transmitted at intervals of one hour on and two hours off from the Research Vessel (R/V) Cory Chouest. The signals were generated from five sources, located 175 meters below the surface at a maximum sound pressure level of 221 decibels (dB).(36) The experiment lasted approximately 4 days, with 35 transmissions. The onset of a gale forced the early termination of the proposed ten day test. Marine mammal monitoring and assessment surveys were conducted prior to and during HIFT from both visual and hydrophone (sonobuoy) platforms in accordance with the NMFS permit and MMC recommendations.(37)

The marine mammal assessment and monitoring program was begun by the R/V Amy Chouest four days prior to HIFT, to establish relative abundance and distribution of marine mammals in the study area.(38) Concurrent visual surveys were conducted during the sound transmissions to assess the effects of HIFT on marine mammals in the area. As recommended by the MMC, transmissions were to be suspended if marine mammals were sighted or heard within one kilometer of the source vessel, marine mammals were sighted or heard within the area ensonified at a level of 160 dB or greater (within about 1.1 kilometers of the source vessel), or any marine mammals were injured. In the latter condition, the experiment was to be suspended until the experimental protocol could be reviewed and revised by NMFS in consultation with the MMC.(39)

The HIFT signal was of sufficient strength to be detected, after computer processing, by 17 of 19 monitoring stations in all five oceans, including along both the East and West U.S. coasts. While HIFT provided valuable acoustic propagation information, its location proved too inaccessible for future studies, and its unique multiple-ocean path through the Antarctic oceanographic front was inappropriate for climate studies.(40) However, HIFT indicated that adequate results could be obtained from less frequent signal transmissions in deeper sound channels. While biological assessment and monitoring were somewhat limited at times by severe weather, there was no indication of harm to marine mammals and no transmissions were suspended. There were possible changes in the distribution of beaked whales and minke whales within 10 kilometers of the HIFT source, while changes in behavior of pilot whales and sperm whales provided unequivocal evidence of behavioral effects of the transmissions; pilot and sperm whales stopped vocalizing completely during the transmissions, or left the area.(41) However, researchers emphasized that sample sizes were insufficient to determine statistically significant changes in the distribution of marine mammals.(42)

Proposed ATOC studies would concentrate on ocean basin distances (5,000-10,000 kilometers), in areas where the sound signal would be less affected by ocean floor topography and oceanographic (frontal) features. This smaller scale would allow for the use of a less intense sound source (195 dB), less than one percent as powerful as the HIFT source. Siting a less intense sound source in a deeper sound channel (about 1 kilometer) is expected to decrease marine mammal exposure.(43)

ACOUSTIC THERMOMETRY OF OCEAN CLIMATE

The Acoustic Thermometry of Ocean Climate project, or ATOC, is primarily a U.S. research program, although 11 institutions from seven nations are involved. ATOC is designed as a 30-month "proof-of-concept" project(44) to provide data for assimilation into, and validation of, climate change models used to help formulate national policies on possible global climate change.(45) It is designed to detect and measure any core ocean warming in the Pacific. If proven valid, other ocean basins (Atlantic, Indian, and Arctic Oceans) may be measured to detect trends in global ocean warming. This $35 million project is funded by the Department of Defense through the Strategic Environmental Research and Development Program with sponsorship by the Advanced Research Projects Agency (ARPA); ARPA is responsible for the management of ATOC.(46)

Sources

ATOC has proposed the use of two sound sources at different locations in the Pacific Ocean. One source will be located 15 kilometers off the coast of Kauai, Hawaii, in 850 meters of water, and a second source will be located on Pioneer Seamount, approximately 88 kilometers west of Point Pillar, California, in 980 meters of water. The California source was originally planned to be located 40 kilometers off the coast of Point Sur, California, in the Monterey Bay National Marine Sanctuary. The Point Sur location had been chosen because of the sound channel's proximity to shore, the existence of Naval hydrophone arrays and land-based support facilities, and the presence of sufficient numbers of marine mammals for Marine Mammal Research Program (MMRP) studies (See "Marine Mammal Research Program" beginning on page 10).(47) Following a recommendation against the Point Sur location by the Sanctuaries and Reserves Division of NOAA, an alternate site (Pioneer Seamount) discussed in the draft environmental impact statement (draft EIS) was proposed instead.(48) Although ARPA contends that the Pioneer Seamount location will cause logistical challenges for both ATOC equipment installation and MMRP assessments because of its increased distance from shore,(49) ATOC's MMRP Advisory Board recommended using mobile sources (rather than the fixed source) for MMRP to increase sample size. Thus, the fixed source need not be located in an area of high marine mammal abundance. Indeed, prudence may suggest the opposite.

The proposed ATOC source signal will be centered at a frequency of 70 Hertz, with a sound pressure level of 195 dB. During a six-month MMRP pilot study, it will be broadcast for 20 minutes every 4 hours for four days, followed by seven days of silence. The schedule will then change to 20 minutes every 4 hours on every fourth day, with possible reductions in broadcast time as sound propagation becomes better understood. U.S. Navy passive hydrophone arrays in the North Pacific and other hydrophone arrays near New Zealand, Point Sur, and Adak, Alaska, will receive the source signal at distances of 3,000-6,000 kilometers.(50)

Permits

On 26 October and 10 December 1993, Scripps Institution of Oceanography applied to NMFS for scientific research permits under the MMPA and the ESA (applications P577 and P577A) to authorize the "taking" of marine mammals in the course of MMRP studies designed to determine how ATOC sound transmission from the Kauai and Point Sur sites might affect marine mammals. The permits would allow, among other things, MMRP marine mammal assessment via aerial surveys and ship-based platforms to address marine mammal safety concerns. The permits would extend through the two years of ATOC and provide for concurrent MMRP studies.(51) In December 1993 and February 1994, MMC reviewed the permit applications, and recommended approval, provided that the project be suspended and reviewed by NMFS and MMC if sound transmissions altered the behavior, distribution, or movement, or affected survivorship or productivity of any marine mammal.(52) MMC also stipulated an evaluation of MMRP's first-year results prior to permit approval for a second year. MMC expressed concerns about the study design and its ability, given limited funds, to resolve uncertainties about marine mammal interactions.(53) The MMRP study protocols were strengthened in response to MMC recommendations. Scripps Institute of Oceanography also applied for other necessary permits for ATOC through the Hawaii Department of Land and Natural Resources, the Hawaii Conservation District, the California Coastal Commission, and the Monterey Bay National Marine Sanctuary.

Marine Mammal Research Program

MMRP was established as part of ATOC, and initially funded through ARPA at $2.9 million. It is presently funded at $4.5 million. MMRP was established to assess the effects of ATOC sound signals on marine mammals at both the Kauai and Point Sur sites. An independent Advisory Board, composed

of five scientists and two "ex officio" members, one from MMC and one from NMFS, was formed to provide advice to MMRP regarding study design.(54) The MMRP Advisory Board met on 15 February, 13 June, and 22-23 September 1994 to review and provide advice on development of the ATOC Marine Mammal Research Program. Except for constraints imposed by limited funding, the design of the Program has been structured to take account of the advice provided by the Advisory Board.(55)

MARINE MAMMAL CONCERNS

Since marine mammals use sound in communicating, navigating, and feeding, much attention has been focused on their possible harm from ATOC sounds. Much of the concern stemmed from questions raised in February and March 1994 by environmental groups, marine mammal scientists, and the public.(56) Their concerns focused on potential hearing damage in whales, the intensity or loudness of the ATOC sources, and confusion over the term "take" in the MMPA. Subsequent concerns were expressed regarding adequacy of baseline data on marine mammals at the Kauai and Point Sur sites; the placement of an ATOC source within the Monterey Bay National Marine Sanctuary; the inability to detect any long-term effects of ATOC on cetaceans such as fecundity, mortality rates, growth rates, etc.; the perceived lack of independence of MMRP scientists from the larger ATOC project; and the lack of study of the potential effects of ATOC on the whole marine ecosystem.

National Research Council Report

In October 1991, NMFS and the Office of Naval Research (ONR) held a workshop on the possible effects of low-frequency, high-intensity sound on marine mammals. Following the workshop, ONR funded a National Research Council (NRC) investigation of current knowledge and research needs in this area.(57) The NRC report, released in March 1994, concluded that there were insufficient scientific data to determine the possible effects of low-frequency sound on marine mammals.(58) The report indicated that many past studies supplied only anecdotal evidence, and lacked data on sound source levels as well as on levels received by the animals. ATOC's MMRP experiments, which some critics believed were less rigorous than those recommended by NRC,(59) were suspended.(60) However, this lack of data was precisely what prompted ATOC critics to recommend de-linking BURP and ATOC, which would allow BURP to proceed independently and well in advance of ATOC. If de-linked, MMRP might provide data to fill these gaps in knowledge prior to committing to ATOC.

Marine mammal hearing tests have been limited to captive species such as belugas, bottlenose dolphins, harp and ringed seals, California sea lions, and Northern fur seals.(61) Therefore, relatively little or nothing is known about the hearing abilities of elephant seals, manatees, polar bears, sea otters, sperm whales, and baleen whales such as humpback and blue whales. The dolphin and pinniped species that have been tested are most sensitive to high frequencies (above 10,000 Hertz). Baleen whales are believed most sensitive to low-frequencies (below 100 Hertz) because their vocalizations are in that frequency range. The NRC report emphasized the need for increased and better studies on wild marine mammal behavior and marine mammal audition, and a review of the MMPA scientific research permitting process, especially with regard to the terms "take" and "harass."(62) The NRC report also urged that scientific permits, issued by NMFS, be broadened beyond the scope of providing only direct benefits for marine mammals.(63)

Sound Pressure Levels

Confusion over sound reference standards sparked much debate concerning the potential effect of ATOC on marine mammals.(64) Sound pressure levels are measured in decibels (dB).(65) The decibel

is measured on a logarithmic scale comparing a measured sound pressure to a reference sound pressure. (66) Since sound reference pressures differ between air and water, a correction factor of 26 dB must be added to an air reference when compared to a water reference. When comparing sound power levels, an additional 35 dB must be added to an air reference to compare sound power levels to a water reference to account for the physical differences between water and air as propagation media. Therefore, approximately 61 dB must be added to an airborne sound to compare it to a waterborne sound. ATOC proponents claim that failure to correct for such differences would erroneously lead one to believe that the ATOC sound source is approximately one million times more powerful (60 dB) than it really is.(67, 68) However, ATOC critics contend that adding the additional 35 dB assumes that power rather than pressure is the appropriate acoustic feature for basing perception of loudness and for auditory damage in marine mammals. These critics believe that pressure is the more relevant feature, as they contend it is in terrestrial mammals. ATOC proponents believe that power rather than pressure level is the more relevant comparison because power levels reflect the change in energy through a given medium over a specified area while pressure levels do not.(69)

Ocean Noise

The acoustic environment in the ocean is not pristine. A variety of noises, both natural and anthropogenic, exist below the surface of the world's oceans.(70,71) However, animals may not be affected adversely by sound unless or until some exposure threshold is exceeded. Most anthropogenic noise is a result of industry and shipping. Geophysical seismic surveys use loud, intensely low-frequency impulsive sounds in oil and gas exploration (212-255 dB). Drilling, construction, and destruction(72) of oil and gas platforms can also produce intense, low-frequency sounds (>185 dB). Noise generated by large tankers and Naval ships (198 dB) is often louder than the ATOC sound source.(73)

Natural geoseismic events, such as undersea earthquakes and seafloor volcano eruptions, can be louder than the ATOC source (>272 dB), although the loudest of these events are comparatively rare. Meteorological sources such as lighting strikes on the ocean's surface, waves breaking at sea, and rain on the ocean's surface, contribute significantly to the ambient or background noise in the ocean (260 dB, 65-85 dB, 30-85 dB, respectively).(74) Biological noise from invertebrates, fish, and mammals also contribute to the ocean's ambient noise levels.(75) The loudest low-frequency moans and pulses of baleen whales may be comparable to the sound levels produced by the ATOC source (185 dB).(76) However, ATOC critics point out that marine mammals likely have evolved and adapted to the natural sounds in the ocean.

Industrial and natural sounds increase the ambient noise levels of the world's oceans.(77) However, noise from surface sources dissipates much faster than noise in the deep sound channel. Critics of ATOC question whether, in an ocean already awash in anthropogenic noise, there is sufficient justification for adding even more unnatural noise (i.e., ATOC) at frequencies used by protected species.

120 dB Criterion

With few exceptions, there is little or no regulation of industrial noise in the oceans. Few studies have provided more than anecdotal accounts of the effects of industrial noise on marine mammals and other biota. A few more substantive studies suggest that at least some cetacean species (e.g., grey, bowhead, and humpback whales) react in detectable ways to sound levels at and below 120 dB.(78,79) The NRC report suggests that NMFS may have adopted this informal "120 dB criterion" for permit reviews involving underwater noise production. NRC emphasizes caution in using this criterion, however, because most industrial, naval, and acoustical research source sounds exceed this level. Whale

behavioral studies indicate large variations with respect to the "120 dB criterion." Different individuals and species responded differently to various levels and types of sound. In addition to the decibel level, characteristics of sound (including the frequency range, duration, and temporal pattern) are important in determining effects on marine mammals.(80)

Marine Mammal Protection Act

Section 104(c)(3) of the MMPA provides that NMFS and FWS may issue permits authorizing the "taking' of marine mammals "to further a bona fide scientific purpose." The term "take" is defined as "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal,"(8l) and "harass" includes any change in behavior by an animal. Thus, both an animal turning its head to look at a researcher and the killing of an animal are regarded as "taking."

Some of the criticism of the proposed ATOC program appears to have resulted from misunderstanding of the term "take." Many people not familiar with the ATOC proposal or the MMPA definition apparently assumed that the term "take" meant to kill or injure, and that approximately one-half million marine mammals could be killed or injured as a result of the proposed ATOC program.(82) However, the MMPA permit applications for ATOC recognize that this number of marine mammals could be harassed or otherwise affected by the sound transmissions, not killed.

RESPONSE TO CONCERNS

In response to concerns expressed by the public, environmental groups, and scientists, as well as by Members of Congress, NMFS held a series of public hearings on MMPA permit applications for ATOC by Scripps Institution of Oceanography.(83) As a result of these hearings, ATOC was delayed until environmental impact statements (EISs) could be prepared. In addition, the MMPA was amended in April 1994 to reflect some questions raised with respect to scientific research permits and harassment,(84) and the National Marine Sanctuaries Program addressed questions about the proposed location of an ATOC source in the Monterey Bay National Marine Sanctuary.(85) ATOC critics believe that public hearings and EISs should have been required as a matter of course for ATOC, due to the lack of data and the scope of the project.

Public Hearings

Public hearings on the Kauai and Point Sur scientific research permit applications (P557 and P557A) were held on 22 March, 14-15 April, and 16 May 1994 in Maryland, California, and Hawaii, respectively. The Senate Committee on Energy and Natural Resources organized a briefing on ATOC for House and Senate staff on 26 April 1994. Among the concerns expressed were questions regarding the effects of low-frequency sound on marine mammals, the baseline data available on marine mammals at both locations, and the placement of a source within the Monterey Bay Sanctuary. Additional concerns were raised about baseline data available for other marine biota, such as fish and sea turtles. As a result, NMFS delayed the permits until ARPA completed EISs for both sites. (86)

Environmental Impact Statements

The Marine Mammal Research Program (MMRP) conducted studies for the EISs under NMFS permits P557B and P577C. The EISs included aerial and shore-based (theodolite) visual surveys, passive acoustic tracking, and individual photographic identification to establish baseline indices prior to beginning ATOC sound transmissions.(87) State and Federal draft EISs for the Kauai and Point Sur sites were prepared, and public hearings were held 6 January and 9-10 February 1995 in California and

Hawaii, respectively. NMFS and ARPA extended the public comment period on the draft EISs until 9 March.(88) ATOC critics charge that the draft EISs will have to be substantially modified to fully comply with the guidelines set by the National Environmental Policy Act (NEPA) and the California Environmental Quality Act.(89)

Marine Mammal Research Program

During a proposed six-month pilot study prior to starting ATOC, MMRP will vary transmission rates, transmission times, and signal strengths of the ATOC sources. These tests will assess the sound field and exposure levels for a few species of marine mammals near the sources.(90) Ambient noise data from commercial and recreational ship traffic and from whale vocalizations will be collected with passive hydrophone arrays. In conjunction with ambient noise baseline data, this test period would allow assessment of the acoustic environment at both sites.(9l) The maximum ATOC source level (195 dB) will be used only if no observable adverse effects are detected among marine mammals.(92) However, critics of ATOC question whether the proposed test period will be sufficient to establish baseline information from which adverse effects on marine mammals can be detected.

Other MMRP components are being pursued to address potential concerns that were raised in the draft EISs. These components include developing audiograms from captive sea turtles and pinnipeds, tests for low-frequency hearing thresholds of captive bottlenose dolphins, Risso's dolphins, and false killer whales,(93) and possibly independent playback of ATOC-type signals to sperm whales in the Azores (a mid-Atlantic island).(94)

The Source

If the six-month MMRP pilot study verifies that the ATOC sound transmissions are likely to have negligible effects on marine mammals, the ATOC source would be authorized to operate one out of every four days over the next two years. The source would transmit for 20 minutes every four hours. With this transmission schedule or duty cycle, the source would be active only about two percent of the total time. The signal would start at 165 dB and be increased six decibels per minute over the next five minutes of the transmission until the maximum level was reached (< 195 dB). This "ramp-up" period would, theoretically, allow marine mammals to move away from the source. Transmissions would be suspended if any adverse or chronic effects were detected by concurrent MMRP studies. The source level would be decreased to the minimum level necessary for signal detection at the receivers. These operating procedures were adopted to decrease the exposure for marine mammals and other biota.(95) However, critics wonder why the project does not start with some minimum-level sound transmission, and increase signal strength gradually until the signal can be detected. Regardless of these provisions, ATOC critics have abiding concerns whether the proposed project could be operated in a fashion that would not adversely affect marine mammals. Furthermore, critics charge that it will be impossible for MMRP to detect the most meaningful chronic effects on fertility, mortality, growth rates, etc. for cetaceans.

Marine Mammal Protection Act

The MMPA was amended in the 103rd Congress with the enactment of Public Law 103-238 on 30 April 1994. Section 104(c)(3) of the Act, as amended in 1994, provides that NMFS and FWS may issue permits authorizing the "taking' of marine mammals "to further a bona fide scientific purpose." The term "take" is defined as "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." The term "bona fide research" is defined as "scientific research on marine mammals, the results of which: (A) likely would be accepted for publication in a refereed scientific

journal, (B) are likely to contribute to the basic knowledge of marine mammal biology or ecology, or (C) are likely to identify, evaluate, or resolve conservation problems."(96)

Section 101(a)(5)(D) of the Act provides that NMFS and FWS may authorize, for periods of as long as one year, the unintentional taking by harassment of small numbers of marine mammals by U.S. citizens incidental to activities (such as the ATOC project) if the taking [harassment]: (1) will have a negligible impact on the affected species or stock, (2) will not have an unmitigable adverse impact on the availability of the affected species or stock for taking by Alaskan Natives for subsistence purposes, and (3) where applicable, the authorization prescribes (a) permissible methods of taking and means for affecting the least practicable impact on the affected species or stock, (b) measures necessary to ensure that there are no unmitigable adverse impacts on the availability of the affected species or stock for taking by Alaskan Natives for subsistence purposes, and (c) requirements for monitoring and reporting to verify that the taking occurs as and when authorized and does not have non-negligible effects. Thus, the basic purpose of ATOC's MMRP is to determine whether the proposed ATOC sound transmissions are likely to result in taking of marine mammals by harassment and, if so, (i) whether the taking would have a negligible effect such that it could be authorized under §101(a)(5)(D) of the Act; and (ii) the type of monitoring and reporting program that would be required to verify that ATOC sound transmissions have negligible impacts on marine mammals.(97)

The Act was amended to expand the definition of " harassment" into Level A and Level B.(98) Level B harassment refers to disturbance without injury of marine mammals or marine mammal stocks, while Level A involves injury to marine mammals or marine mammal stocks. Scientific research involving only Level B harassment will be exempt from the formal MMPA permitting process. These changes should encourage a broader range of marine mammal research as well as expedite the permitting process, although their long-term effects on marine mammal populations is uncertain. If there were sufficient reason to believe that the ATOC project would involve only Level B harassment, the project could be authorized under §101(a)(5)(D) and there would be no need for either MMRP or a scientific research permit.

Monterey Bay National Marine Sanctuary

The Sanctuaries and Reserves Division within NOAA's National Ocean Service considered locating the proposed California source site within the Monterey Bay National Marine Sanctuary inappropriate and recommended against it, despite support for scientific research from the Sanctuary's Advisory Council. (99, 100) As authorized by Title III of the Marine Protection, Research, and Sanctuaries Act, research is an important goal of the National Marine Sanctuaries Program. However, the Sanctuaries and Reserves Division concluded that uncertainties in assessing the potential environmental risk from ATOC made it difficult to decide whether ATOC's research activities would meet the Sanctuary's highest priority goal: "protection of its marine environment, resources, and qualities."

CONCLUSIONS

The Acoustic Thermometry of Ocean Climate (ATOC) project is unique among underwater acoustic experiments because it proposes to determine the extent of core ocean warming with low-frequency sound. The lack of information on the effects of low-frequency sound on marine mammals is evident. In response to concerns expressed during public hearings, ATOC's Marine Mammal Research Program (MMRP) prepared EISs for the proposed Kauai and Point Sur source sites. MMRP and other component studies or comparable research can provide substantive information on the effects of low-frequency sounds on marine mammals. However, critics of ATOC argue that MMRP should be delinked from the ATOC project to provide this substantive information prior to the consideration of

ATOC permits.

In consultation with NMFS, the Marine Mammal Commission, and the MMRP advisory board, ARPA included mitigation measures in the draft EISs to alleviate potential harm to marine mammals. ARPA proposed to reduce ATOC transmission time, gradually increase the intensity of the source at the beginning of each transmission, adjust the sources to the minimum sound pressure level necessary for the receiving stations, and increase the depth of the sound sources. In addition, ARPA will modify ATOC's experimental protocol if any detrimental reactions are observed by marine mammals during concurrent MMRP studies. However, critics of ATOC believe less-obvious or longer-term reactions might not be observed or recognized.

Congress may want to consider ATOC with regard to risk assessment and regulatory reform goals. An objective assessment of costs in terms of effects on marine mammals and possibly the entire deep ocean ecosystem versus the benefits of potential gains in global warming information is not easy. It is unclear what the effects of increased ocean warming could have on marine mammals and other biota. With respect to the MMPA and the ESA, the question of how to weigh the value of many species (i.e., the deep ocean ecosystem) versus the potential long-term economic and environmental costs and benefits to public and private sectors is difficult to answer.

It is unlikely that ATOC, without the scientific research in MMRP, would be eligible for a small-take authorization under §101(a)(5)(D) of the MMPA, as amended. It is unclear whether other oceanographic non-marine mammal research activities related to ATOC, which may by definition "take" marine mammals under Level B harassment, will require scientific research or small-take authorization permits.

Will concern surrounding ATOC result in new standards being established regarding the limits on noise introduced into the marine environment? If so, will these standards lead to regulations limiting noise from non-marine mammal oceanographic research as well as from industries such as shipping and exploring and developing oil and gas resources? What would be the benefits of noise regulations protecting marine mammals and what would be the economic costs to the private and public sectors? On what basis would noise exposure limits be set? Human noise exposure limits for airborne sound are set by the Occupational Safety and Health Administration (OSHA) within the Department of Labor, and are based on scientific evidence regarding temporary and permanent hearing loss in humans. However, no similar studies have been published for effects on marine mammals.(101)

Finally, Congress may review ATOC with respect to amending the Marine Protection, Research, and Sanctuaries Act to establish standards or criteria for what scientific research might be permissible within sanctuaries.

Endnotes

1. Troy Sparks, Public Policy Intern from Texas A&M University, researched and wrote the draft of this report under the supervision of Eugene H. Buck, Senior Analyst in Natural Resources Policy.
2. Baggeroer, A., and W. Munk. "The Heard Island Feasibility Test," *Pays. Today* (Sept. 1992): 22-30; U.S. Library of Congress, Congressional Research Service. *Global Climate Change.* [by J.R. Justus and W.A. Morrissey.] CRS Report No. IB89005. Washington, DC. 1995. 15 p.; Roemmich, D., and J. McGowan. "Climatic Warming and the Decline of Zooplankton in the

California Current." *Science, v.* 267 (1995): 1324-1326; Taubes, G. "Is a Warmer Climate Wilting the Forests of the North?" *Science, v.* 267 (1995): 1595.

3. Munk, W., and C. Wunsch. "Ocean Acoustic Tomography: A Scheme for Large Scale Monitoring," *Deep Sea Research* (1979): 123-161; Munk, W., W. O'Reilly, and J. Reid. "Australia-Bermuda Sound Transmission Experiment (1960) Revisited," J. *Pays. Oceanogr., v.* 18 (1988): 1876-1898.
4. Botzum, J.R., ed. *Ocean Science News, v.* 32, no. 6 (31 Dec. 1990). Washington, DC. 4 p.
5. Pub.L. 92-522, 86 *Stat.* 24. 1027, 16 *U.S.C.* 1361-1407.
6. Pub.L. 93-205, 87 *Stat.* 884, 16 *U.S.C.* 1531-1543.
7. Although beyond the scope of this report, debate also has arisen concerning the likelihood that global warming could cause detectable changes in ocean water temperature, that the ATOC project will be able to detect any temperature changes of the magnitudes necessary to be useful, and whether the proposed ATOC project is the most cost-effective means for doing so.
8. National Research Council. *Low-frequency Sound and Marine Mammals: Current Knowledge and Research Needs.* Committee on Low Frequency Sound and Marine Mammals Oceans Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council. Washington, DC: National Academy Press, 1977. 75 p.
9. U. S. Library of Congress, Congressional Research Service. *The Marine Mammal Protection Act: Reauthorization Issues,* [by J. Heck and E. Buck.] CRS Report No. 92-728 ENR. Washington, DC: 1993. 22 p.
10. Keeling, C., et al. "A Three-Dimensional Model of Atmospheric CO2 Transport Based on Observed Winds: I. Observational Data and Preliminary Analysis." In: *Aspects of Climate Variability in the Pacific and the Western Americas.* [D.H. Peterson, ed.] Geophysical Monograph, v. 55. Washington, DC: American Geophysical Union, 1989. p. 165-236; Neftel, A., E. Moor, H. Oeschger, and B. Stauffer. "Evidence from Polar Ice Cores for the Increase in Atmospheric CO2 in the Past Two Centuries," *Nature, v.* 315 (1985): 45-47.
11. CRS Report No. IB89005, *loc. cit.*
12. CO2 accounts for the majority of green house gas emissions. However, methane, nitrous oxide, and CFCs are projected to collectively contribute as much as CO2 to global warming over the next 60 years. (U.S. Library of Congress, Congressional Research Service. *Climate Change Action Plans.* [by L.B. Parker, and J.E. Blodgett.] CRS Report No. 94-404 ENR. Washington, DC: 1994. 25 p.).
13. Hansen, J., and S. Lebedeff. "Global Trends of Measured Surface Air Temperature." J. *Geophys. Res., v.* 92, no. 13 (1987): 345-372.
14. Munk, W. "The Heard Island Experiment," *Naval Res. Rev., v.* 1(1991): 2-22.
15. Hansen and Lebedeff, *loc. cit.*
16. Munk, O'Reilly, and Reid, *loc. cit.*.
17. Munk, *loc. cit.*
18. Yam, P. "The Man Who Would Hear Ocean Temperatures," *Scientific American* (January 1995): 38-40.

19. Munk, W., A. Baggeroer, and T.G. Birdsall. "The Heard Island Feasibility Test," J. *Acoust. Soc. Am., v.* 96, no. 4 (October 1994): 2330-2342.

20. Urick, R.J. *Principles of Underwater Sound* (3rd ed). New York, NY: McGraw-Hill, Inc. 1983. 423 p.; Pickard, G.L., and W.J. Emery. *Descriptive Physical Oceanography: An Introduction (5*th (SI) ed). New York, NY: Pergamon Press, 1990. 320 p.

21. Low-frequency sound signals can be detected across ocean basins provided that the source level is loud enough to be detected at its receiving station(s). Because the received level of the projected signal is below the background (ambient) noise level of the ocean in most acoustic thermometry proposals,

computer processing is required to detect the encoded signal.

22. Baggeroer and Munk, *loc. cit.*

23. Spindel, R.C., and P.F. Worcester. "Ocean Acoustic Tomography: A Decade of Development," *Sea Technology* (July 1991): 47-52.

24. Munk, *loc. cit.*

25. Alper, J. "Munk's Hypothesis: A Slightly Mad Scheme to Measure Global Warming," *Sea Frontiers* (January 1991): 38-43, 63.

26. Andrews, J.E. *The Heard Island Acoustic Tomography Experiment.* International Science Lecture Series, Inaugural Lecture, ESNIB 90-09. September 1990. p. 20-25.

27. Baggeroer and Munk, *loc.. cit.*

28. Holl, Manfred M. *A Critique of the Acoustic Thermometry of Ocean Climate (ATOC) Experiment.* Carmel, CA: White paper draft, May 26a, 1994. 5 p.

29. Alper, *loc. cit..*

30. Munk, O'Reilly, and Reid., *loc. cit..*

31. Birdsall, T.G., K. Metzger, and M.A. Dzieiuch. "Signals, Signal Processing, and General Results," *The J. Acoust. Soc.. Am., v.* 96, no. 4 (October 1994): 2353-2356.

32. Gibbons, A. "What's the Sound of One Ocean Warming?" *Science, v.* 248 (6 April 1990): 33-34.

33. Munk, Baggeroer, and Birdsall, *loc. cit.*

34. Anderson, I. "Global Hum Threatens to 'Deafen' Whales," *New Scientist (19* January 1991):

35. The MMC determined that marine mammals could possibly be affected by HIFT sound transmissions at distances exceeding 1000 kilometers from the signal source. Since insufficient data were available to determine the number of species affected, as well as how they could be affected, the HIFT experimental design was changed to include marine mammal monitoring and assessment.

36. The decibel (dB) is a logarithmic scale comparing a measured sound pressure to a reference sound pressure. An increase of 10 dB represents a 10-fold (one order of magnitude) increase in sound pressure level, an increase of 20 dB represents a 100-fold (two orders of magnitude) increase, and a 30 dB increase represents a 1000-fold (three orders of magnitude) increase, etc. Sound pressures are measured in Pascals (Newtons per meter2). Unless otherwise stated, all sound pressure levels are referenced at 1 uPascal (micro-Pascal or 10-6 Pascals) at 1 meter.

37. Munk, Baggeroer, and Birdsall, loc. *cit.;* Bowles, A.E., M. Smultea, B. Wursig, D.P. DeMaster, and D. Palka. "Relative Abundance and Behavior of Marine Mammals Exposed to Transmissions from the Heard Island Feasibility Test," J. *Acoust. Soc. Am., v.* 96, no. 4 (October 1994): 2469-2484.

38. *Ibid.*

39. *Ibid.*

40. Munk, Baggeroer, and Birdsall, *loc. cit.*.

41. Bowles, et al., *loc.cit.*

42. *Ibid.*

43. Munk, Baggeroer, and Birdsall, *loc.. cit.*

50. Munk, Baggeroer, and Birdsall, *loc. cit.;* ATOC: Technical Background Report, *loc. cit.*

51. Marine Mammal Commission, *loc. cit.; U.S.* Department of Commerce, NOAA, NMFS, Office of Protected Resources. *Marine Mammal Protection Act of 1972 Annual Report (1 January 1992 to 31 December 1993).* Silver Spring, MD. p. 75-76.

52. Critics question whether any experimental design could determine cetacean survivorship or productivity, with the exception of direct and immediate mortality.

53. Marine Mammal Commission, *loc. cit.*

54. *Ibid.*

55. *Ibid.*

56. Shurkin, J. "Pacific Sound Experiment Faces Heat," *Nature, v.* 368 (7 April 1994): 485.

57. Marine Mammal Commission, *loc. cit.*

58. National Research Council, *op. cit., p.* 17-18.

59. Among other topics and approaches for future research, NRC recommended a one-year baseline study, that species in the food chain supporting marine mammals also be studied, and that individual animals serve as their own controls.

60. Schmidt, K. "ATOC Delayed as Report Laments Research Gaps," *Science, v.* 264 (15 April 1994): 339-340.

61. National Research Council, *op. cit., p.* 13-17.

62. National Research Council, *op. cit., p.* 40-48.

63. National Research Council, *op. cit., p* 25-39.

64. Paddock, R. "Undersea Noise Could Risk Making Whales Deaf," *Los Angles Times* (22 March 1994): A1.

65. The standard reference sound pressure in air is 20 micro-Pascals (uPa) which is approximately the threshold of human hearing measured from a distance of one meter (20 uPa at 1 meter) for a 1,000 Hertz tone. The standard reference sound pressure in water is 1 uPa at 1 meter.

66. Urick, R.J., *loc. cit.*

67. In other words, 195 dB in air radiates 250 million watts while 195 dB in water radiates 250 watts.

68. U.S. Department of Defense, ARPA. *Draft Environmental Impact Statement for the Kauai Acoustic Thermometry of Ocean Climate Project an its associated Marine Mammal Research Program.* Arlington, VA: December 1994. p. 1-10 to 1-13.

69. Because of the impedance differences between air and water, actual power level comparisons (in watts) differ while the pressure level remains the same. see footnote 67, noting that the pressure level is the same at 195 dB while power levels are vastly different.

70. Urick, R.J., *op. cit.., p.* 202-236.

71. Power levels in this section are given for a frequency range of 10 to 1000 Hertz.

72. In 1989, the American Petroleum Institute pursued small-take authorizations from NMFS for the removal of oil and gas platforms in the Gulf of Mexico under section 101(a)(5)(A) of the MMPA. Small-take authorizations were requested because the explosives used during platform removal could result in harassment, injury, or death of marine mammals close to the platforms. Approximately 670 structures are scheduled for removal during the first 5 years of authorization. On 16 August 1993, MMC provided comments to NMFS regarding the concerns about the appropriate safety distance for marine mammals and other biota from the explosion, the number of species that may be affected and how they would be affected, the detection and monitoring of marine mammals and other biota within and outside the safety zone, and the indirect effects of platform removal on marine mammals and other biota such as hazardous substances in the sediments under the platforms. A final rule is expected from NMFS and MMC in 1995. (Marine Mammal Commission, *loc. cit., p.* 196-202).

73. ARPA, *Kauai Draft EIS, loc. cit.*

74. *Ibid.;* Urick, R.J., *loc. cit.*

75. *Ibid.*

76. ARPA, *Kauai Draft EIS, loc. cit.*

77. Urick, R.J., *loc. cit.*

78. National Research Council, *op. cit., p.* 18-21.

79. ATOC researchers have used models to estimate the 120 dB "zone of influence" (received levels) at distances as far as 12 and 25 kilometers for the shoreward side and as far as 7.5 and 12 kilometers for the oceanward side of the Kauai and Point Sur sites, respectively. (ARPA, *Kauai Draft EIS, op. cit., p.* 2-5 to 2-13; ARPA, *California Draft EIS, op. cit., p.* 2-6 to 2-12).

80. National Research Council, *loc. cit.*

81. CRS Report No. 92-728 ENR, *loc.. cit.*

82. Potter, J.R. "ATOC: Sound Policy or Enviro-Vandalism? Aspects of a Modern Media-Fueled

Policy Issue," J. *Environ. Devel., v.* 3, no. 2 (1994): 47-62.

83. Broad, W. "Environmental Camps Feud Over Noisy Ocean Experiment," *The New York Times* (5 April 1994): C4.

84. U.S. Library of Congress. Congressional Research Service. *Marine Mammal Protection Act Amendments of 1994.* [by Eugene H. Buck.] CRS Report No. 94-751 ENR. Washington, DC Sept. 28, 1994. 11 p.

85. Personal communication with Dept. of Commerce, NOAA, Office of the Comptroller, *loc. cit.*

86. Marine Mammal Commission, *loc. cit.*

87. ARPA. *Kauai Draft EIS, op. cit.,* p. C-1 to C-32; ARPA. *California Draft EIS, op. cit., p.* C-1 to C41.

88. ATOC Project Office, Scripps Institution of Oceanography, University of California, San Diego. *ATOC Activity Report.* La Jolla, CA: February 1995. 7 p.

89. ARPA, *California Draft EIS, op. cit., p.* 1-23 to 1-27.

90. Estimates of sound levels at different distances from the sources will be verified and monitored by stationary sonobuoys and passive-towed arrays.

9l. ATOC Project Office, Scripps Institution of Oceanography, University of California, San Diego. *ATOC Activity Report.* La Jolla, CA: September 1994. 5 p.

92. ARPA, *California Draft EIS, op. cit., p.* 2-36 to 2-39.

93. *ATOC Activity Report,* September 1994, *loc. cit.*

94. Since the researcher proposing the Azores test is not a U.S. citizen, a U.S. MMPA permit is not required.

95. ARPA, *California Draft EIS, loc. cit.*

96. 16 U.S. Code 1362(22).

97. Personal communication with the Marine Mammal Commission, Washington, DC 31 March 995.

98. CRS Report No. 92-728 ENR, *loc. cit.*

99. Personal communication with Dept. of Commerce, NOAA, of fine of the Comptroller, *loc. cit.*

l00. The Advisory Council provides recommendations to the Sanctuary manager, and is comprised of working groups on research, education, and conservation. Upon review of ATOC, the SAC research working group was unable to reach any conclusions regarding the "nature and extent of the risks to the resources inherent in the ATOC project." However, the research group "reiterated their support of scientific research" within the Sanctuary. After a review of the ATOC draft EISs, the Sanctuary manager and higher-level decision-makers concluded that there was insufficient evidence of negligible

short-term effects on Sanctuary biota for recommendation of the site. (Personal communication with Dept. of Commerce, NOAA, Office of the Comptroller, *loc. cit.)*

101. Natural Research Council, *op. cit.*, p. 21.

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